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Echols

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[54] **GRAVEL PACK APPARATUS**
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[52] **U.S. Cl.** **166/242.7; 166/377**
[58] **Field of Search** 166/377, 380,
166/242.6, 242.7; 285/3, 18

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[57] **ABSTRACT**

A gravel pack apparatus and associated method of completing subterranean wells provides convenient and economical gravel packing operations, permitting a sand control screen to be run into the well attached to the apparatus which is, in turn, attached to production tubing, and further permitting the tubing to be detached from the screen. In a preferred embodiment, a gravel pack apparatus has interoperable valve and tubing release portions. The valve portion may be closed after the gravel packing operation is completed. Closure of the valve portion activates the release portion, permitting the apparatus to be separated.

8 Claims, 7 Drawing Sheets

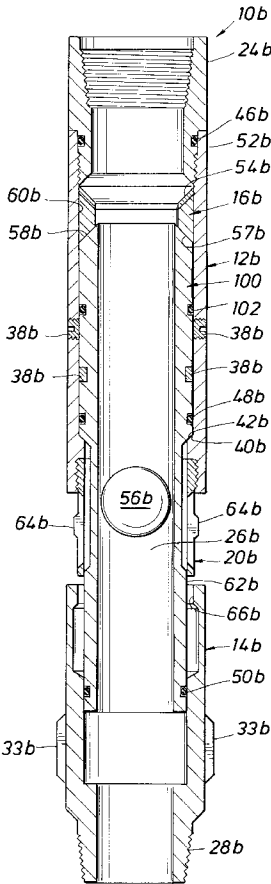
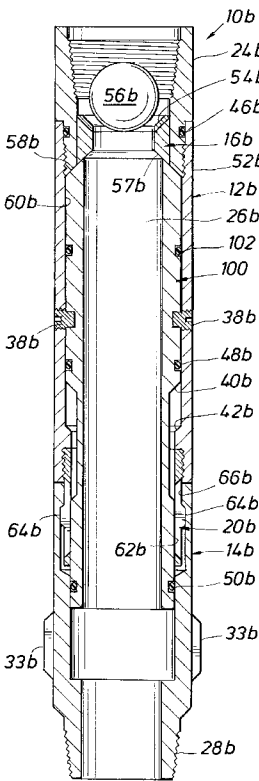


FIG. 1A

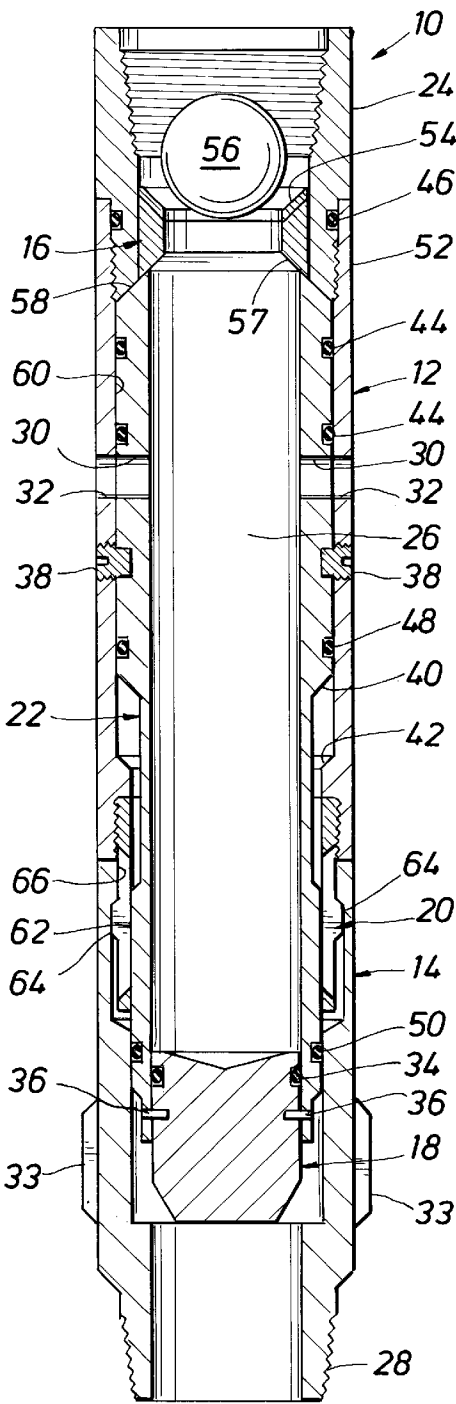


FIG. 1B

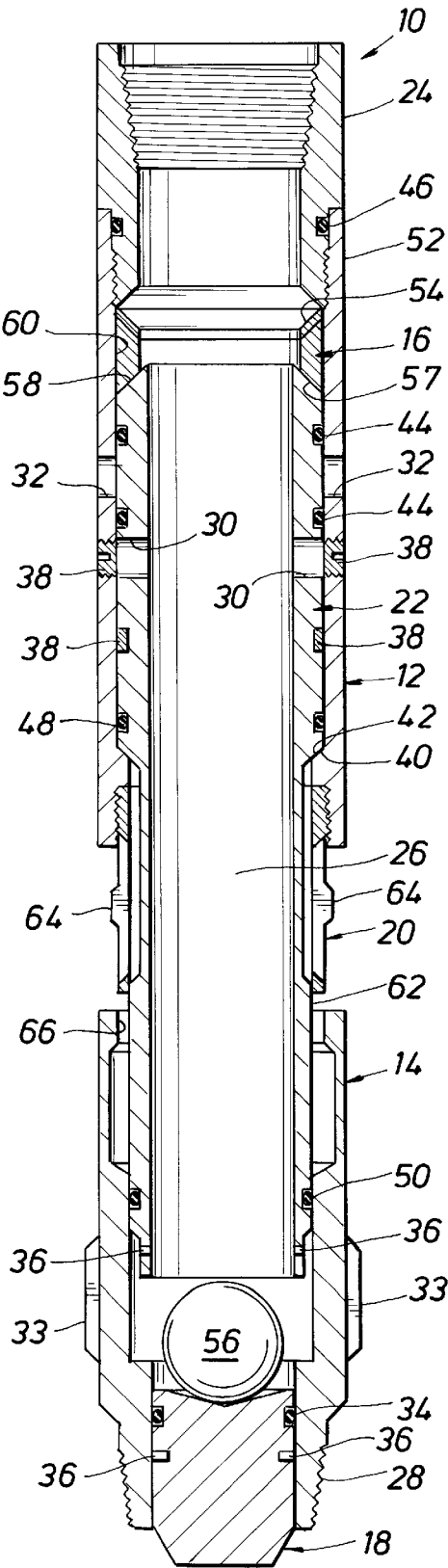


FIG. 2A

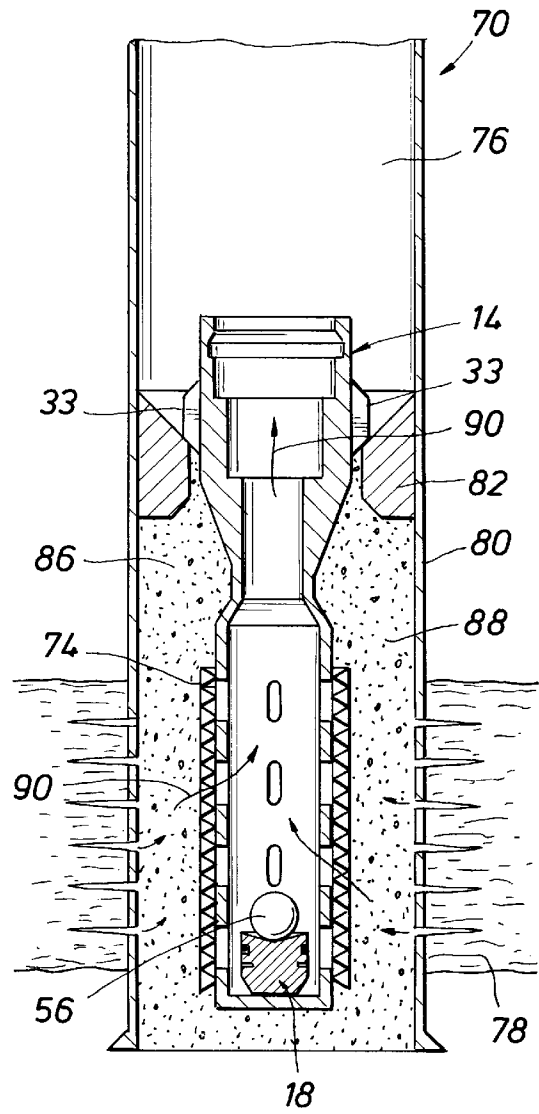
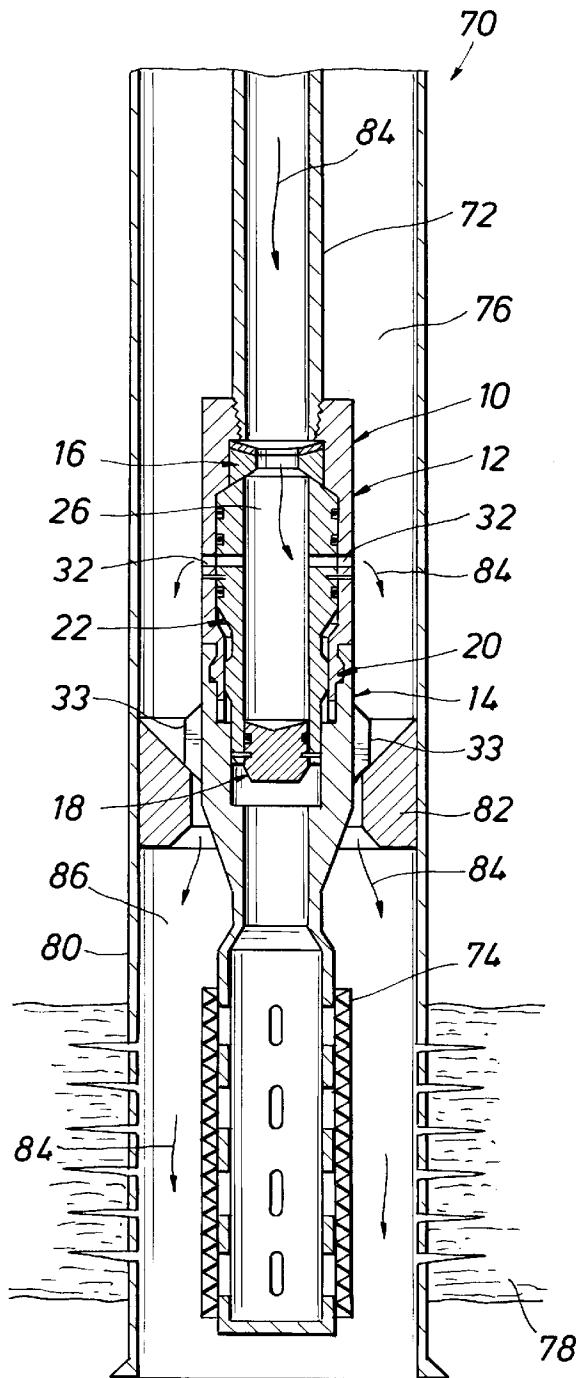


FIG. 2B

FIG. 3A

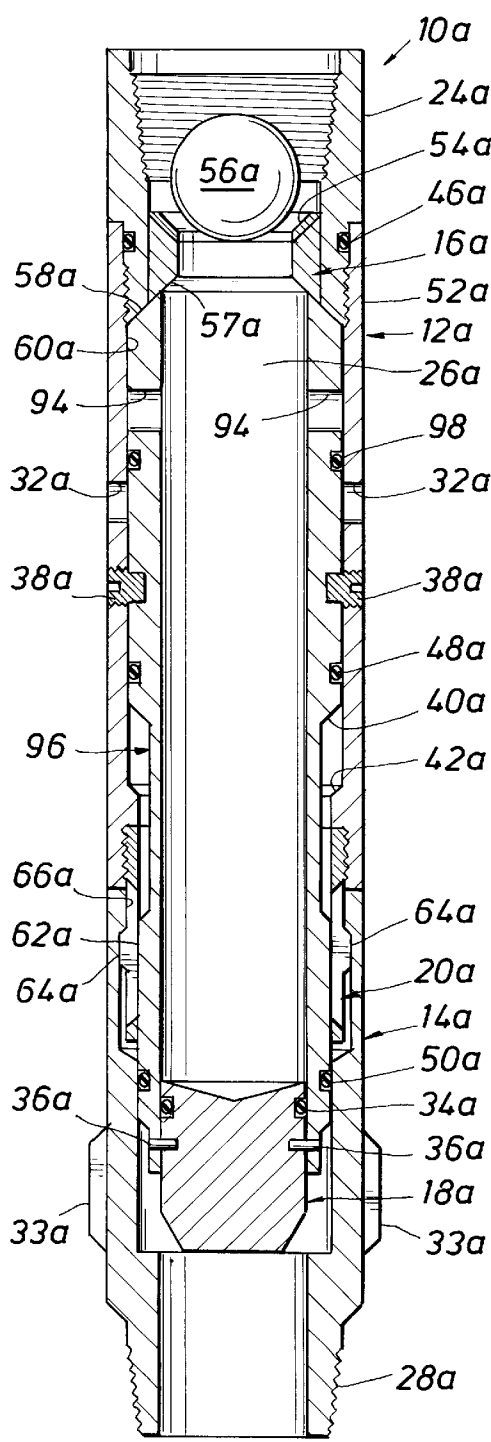


FIG. 3B

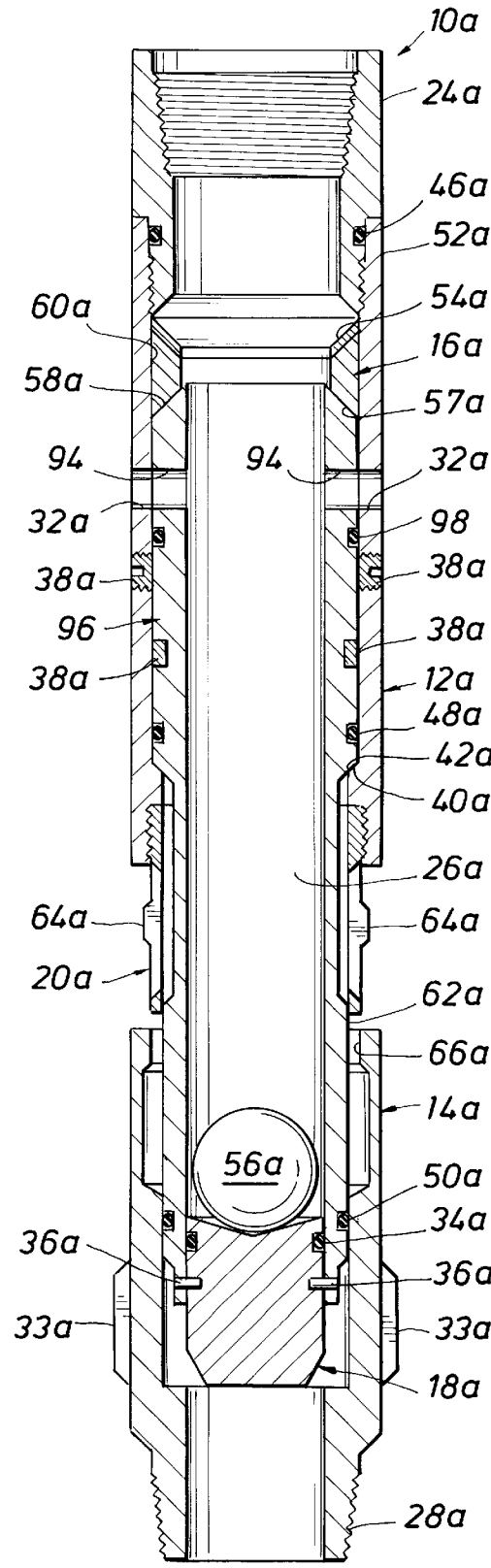


FIG. 4A

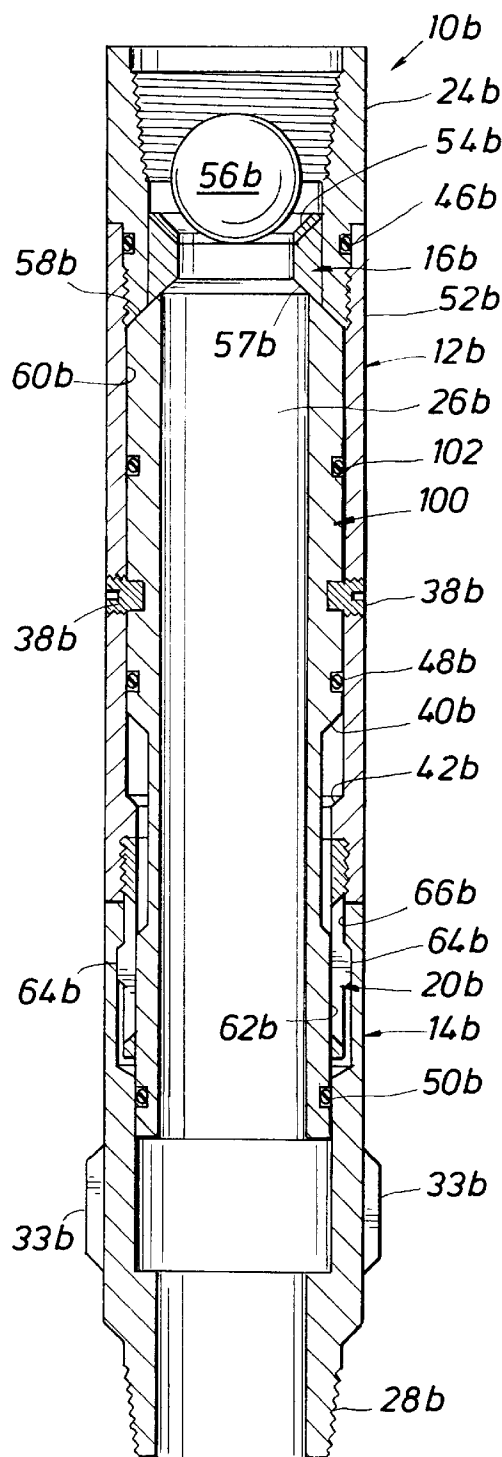
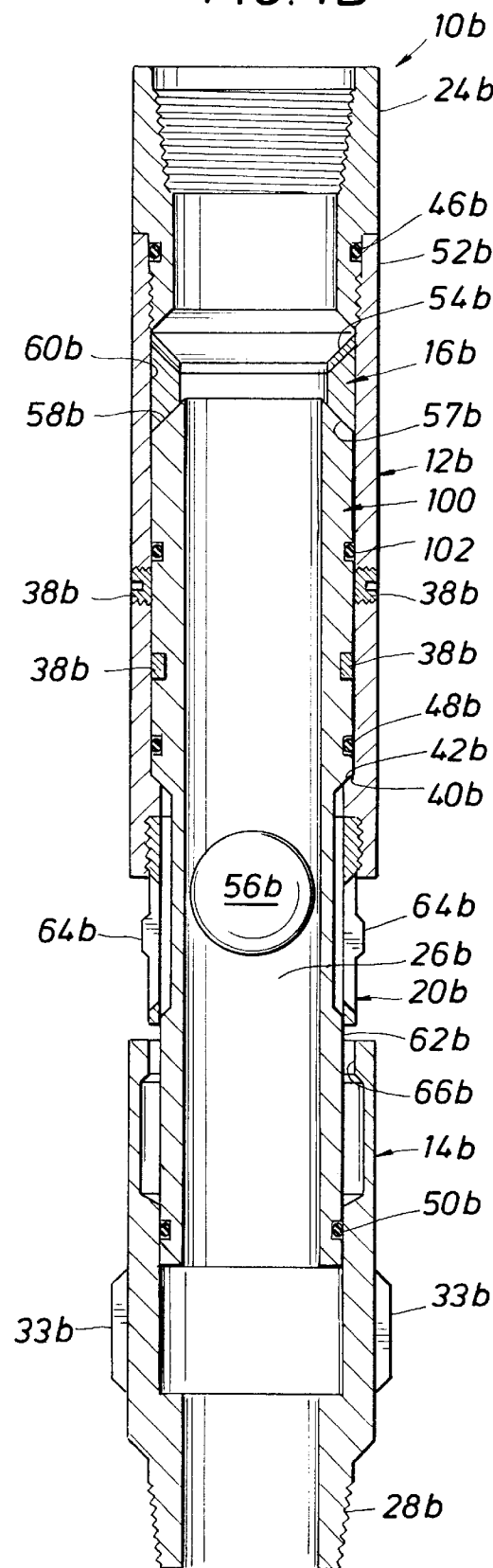


FIG. 4B



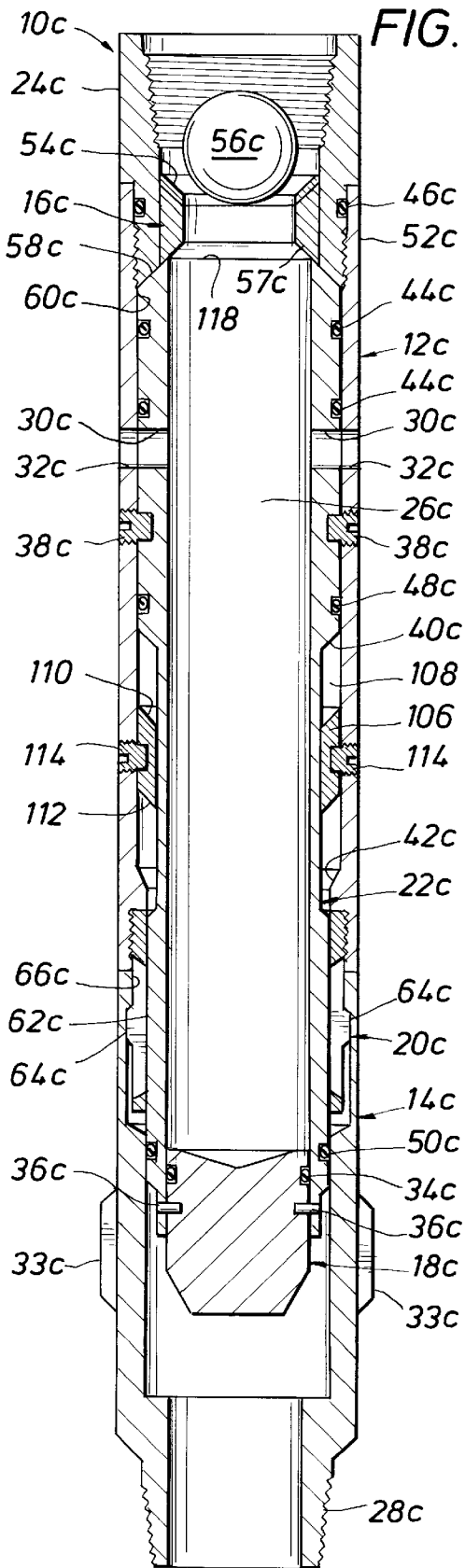
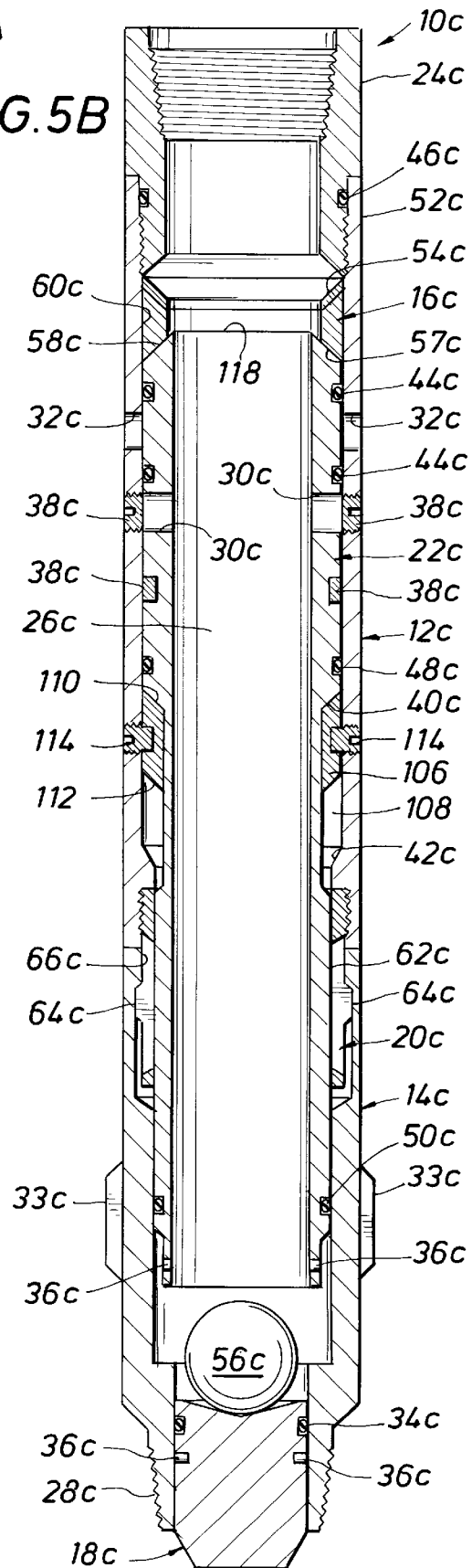


FIG. 5B



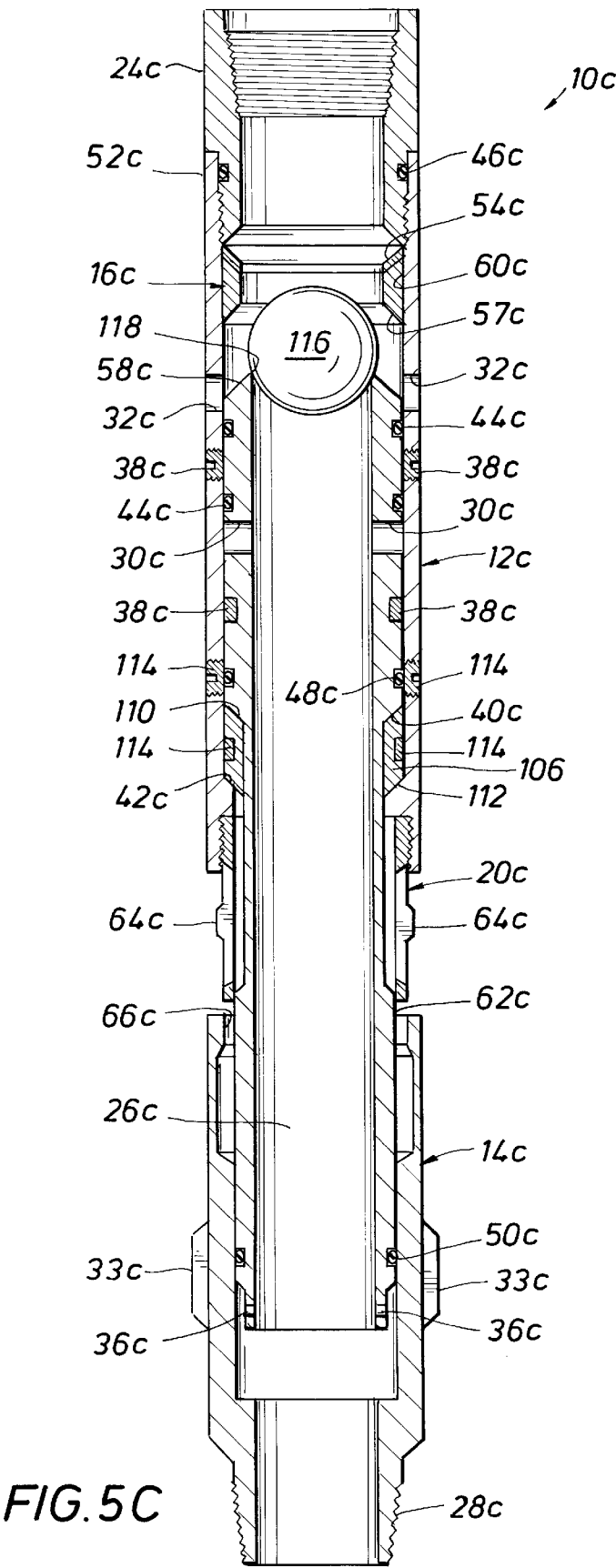


FIG. 6A

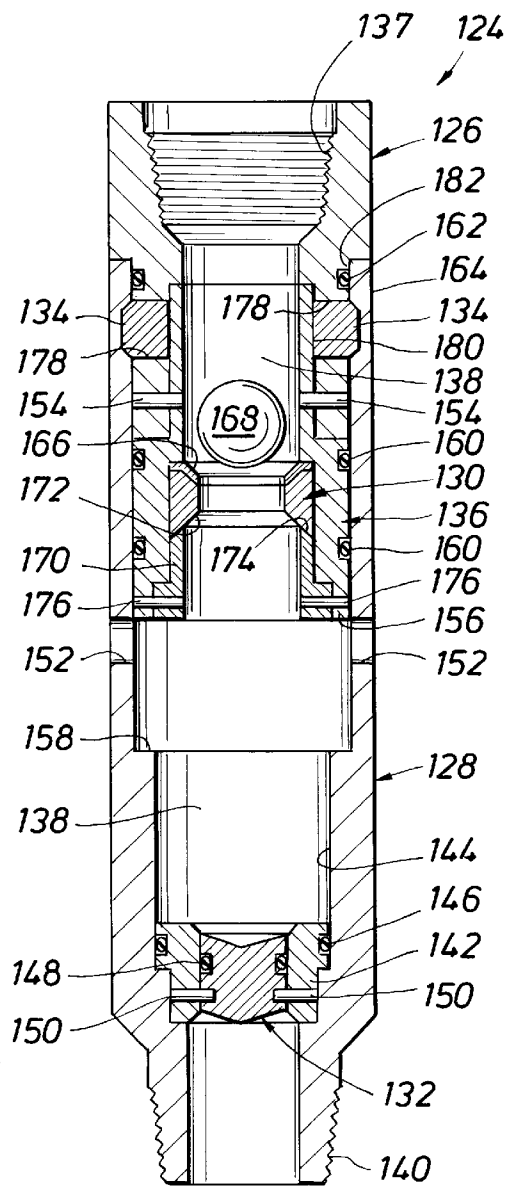
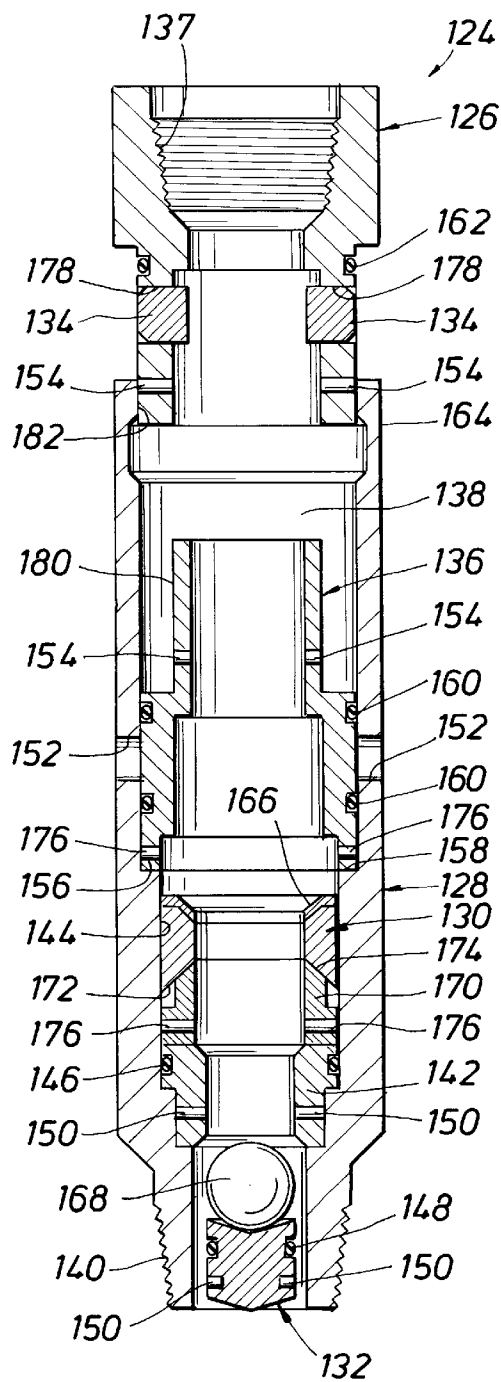


FIG. 6B



GRAVEL PACK APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates generally to tools used to complete subterranean wells and, in a preferred embodiment thereof, more particularly provides apparatus for use in gravel pack operations and methods of using same.

Gravel pack operations are typically performed in subterranean wells to prevent fine particles of sand or other debris from being produced along with valuable fluids extracted from a geological formation. If produced (i.e., brought to the earth's surface), the fine sand tends to erode production equipment, clog filters, and present disposal problems. It is, therefore, economically and environmentally advantageous to ensure that the fine sand is not produced.

In the subterranean well, a tubular protective casing usually separates the formation containing the fine sand particles from the wellbore. The casing is typically perforated opposite the formation to provide flowpaths for the valuable fluids from the formation to the wellbore. If production tubing is simply lowered into the wellbore and the fluids are allowed to flow directly from the formation, into the wellbore, and through the production tubing to the earth's surface, the fine sand will be swept along with the fluids and will be carried to the surface by the fluids.

Conventional gravel pack operations prevent the fine sand from being swept into the production tubing by installing a sand screen on the end of the production tubing. The wellbore in an annular area between the screen and the casing is then filled with a relatively large grain sand (i.e., "gravel"). The gravel prevents the fine sand from packing off around the production tubing and screen, and the screen prevents the large grain sand from entering the production tubing.

A problem, which is present in every conventional gravel pack operation, is how to place the gravel in the annular area between the screen and the casing opposite the formation. If the screen is merely attached to the bottom of the production tubing when it is installed in the wellbore, the gravel cannot be pumped down the production tubing because the screen will prevent it from exiting the tubing. The gravel cannot be dropped into the wellbore annular area from the earth's surface because a packer is usually installed between the production tubing and the casing above the formation, and this method would be very inaccurate in packerless completions as well.

One solution has been to run the production tubing into the wellbore without the screen being attached to the tubing. A landing nipple is installed at or near the bottom of the tubing before running the tubing into the well. When the landing nipple has been properly positioned above the formation, a screen is lowered into the tubing from the earth's surface on a slickline or wireline. The screen is landed in the nipple in the tubing so that it extends outwardly and downwardly from the tubing and is positioned opposite the formation. Gravel is then pumped down the tubing from the earth's surface, through a small space between the nipple and the screen, and outwardly into the annular area between the screen and the casing opposite the formation. This method is known as "through tubing gravel packing", since the gravel is pumped through the tubing.

This method has several disadvantages, however. One disadvantage is that the screen must be installed into the tubing as a separate operation. This requires coordination with a slickline or wireline service, time spent rigging up and rigging down special equipment such as lubricators

needed for these operations, and the inability to conveniently perform such operations in wells which are horizontal or nearly horizontal. In some instances, the screen is run in with the tubing, already landed in the nipple in the tubing. In those instances, a slickline operation is still needed to retrieve the screen from the tubing.

Another disadvantage of the above method is that the screen must be able to pass through the tubing. This means that the size of the screen (at least its outer diameter) can be no larger than the tubing's inner drift diameter. In order to have a sufficiently large screen surface area, very long screens must sometimes be utilized with this method. Additionally, since there is usually only a very small radial gap between the screen (or the slickline tool used to place the screen in the nipple) and the landing nipple, only a very small flow area is available for pumping the gravel out of the tubing and into the annular area of the well.

Yet another disadvantage of the above method is that the tubing may not be conveniently removed from the wellbore for replacing the packer, completing other formations in the well, maintenance, etc. The method requires the screen to be removed along with the tubing, or the screen must be removed by wireline or slickline prior to removing the tubing. In either case, the gravel pack will be destroyed as the gravel falls into the void created when the screen is removed.

From the foregoing, it can be seen that it would be quite desirable to provide apparatus for gravel pack operations which does not require the screen to be positioned as a separate operation and does not require the screen to pass through the tubing, but which provides a large flow area for pumping the gravel into the annular area of the well and provides for convenient detachment of the tubing from the screen for removal of the tubing from the wellbore. It is accordingly an object of the present invention to provide such apparatus and associated methods of using same.

SUMMARY OF THE INVENTION

In carrying out the principles of the present invention, in accordance with an embodiment thereof, gravel pack apparatus is provided which is a unique valve and release mechanism. The valve permits pumping gravel therethrough with the screen attached to the bottom of the tubing, and the release mechanism permits convenient detachment of the tubing from the screen.

In broad terms, apparatus is provided which includes tubular first and second housings, a ball seat, a plurality of collets, a flow passage and a tubular sleeve. The second housing is coaxially disposed relative to the first housing, with an end of the first housing being proximate an end of the second housing. The flow passage extends through the first and second housings.

The collets extend axially between the first housing and the second housing and releasably secure the first housing against axial displacement relative to the second housing. The tubular sleeve is coaxially disposed within the first and second housings and has an outer diameter radially inwardly adjacent the collets. The sleeve outer diameter radially outwardly biases the collets, and the sleeve is disposed adjacent the ball seat, such that the sleeve is capable of axial movement relative to the collets when a pressure differential is created across the ball seat.

Additionally, apparatus is provided which includes tubular first and second housings, a ball seat, a lug, a flow passage, and a tubular sleeve. The flow passage extends through the first and second housings.

The first housing has an end portion and a radially extending opening formed through the end portion. The second housing has an end portion radially outwardly and coaxially disposed relative to the first housing end portion.

The lug extends radially through the opening and between the first housing end portion and the second housing end portion. The lug releasably secures the first housing against axial displacement relative to the second housing.

The tubular sleeve is coaxially disposed within the first housing. It has an outer diameter radially inwardly adjacent the lug which radially outwardly biases the lug. The sleeve is disposed adjacent the ball seat, such that the sleeve is capable of axial movement relative to the lug when a pressure differential is created across the ball seat.

A method of completing a subterranean well having a wellbore intersecting a formation is also provided, which method includes the steps of providing a gravel pack device, providing production tubing, attaching the gravel pack device to the production tubing, and inserting the gravel pack device and production tubing into the wellbore.

The gravel pack device includes first and second tubular housings, a collet member releasably securing the first tubular housing in a coaxial and adjoining relationship with the second tubular housing, an expandable circumferential seal surface, an internal flow passage extending axially through the seal surface and the first housing, and a tubular sleeve having an outer side surface. The tubular sleeve has a first position, in which the sleeve outer side surface radially biases the collet member to secure the first and second housings against axial displacement therebetween, and a second position, axially displaced relative to the collet member from the first position, in which the sleeve outer side surface unbiases the collet member to release the first and second housings for axial displacement therebetween.

The seal surface is capable of biasing the sleeve to axially displace from the first position to the second position when a pressure differential is created across the seal surface. The method also includes the steps of creating the pressure differential across the seal surface and releasing the first and second housings for axial displacement therebetween.

Additionally, a method of gravel packing a formation intersected by a subterranean wellbore is also provided. The method includes the steps of providing a device, production tubing, and a sand control screen, attaching the device between the tubing and the sand control screen, and inserting the tubing, device, and sand control screen into the wellbore.

The device includes first and second tubular housings, a ball seat, collets, a flow passage, a plug releasably secured in the flow passage, a flow port, and a tubular sleeve. The second housing is coaxially disposed relative to the first housing with an end of the first housing being proximate an end of the second housing. The ball seat is coaxially disposed within the first housing. The flow port is capable of permitting fluid communication between the flow passage and the wellbore.

The collets extend axially between the first housing end and the second housing end and releasably secure the first housing against axial displacement relative to the second housing. The sleeve is coaxially disposed within the first and second housings and has an outer diameter radially inwardly adjacent the collets. The sleeve outer diameter radially outwardly biases the collets, and the sleeve is disposed adjacent the ball seat, such that the sleeve is capable of axial movement relative to the flow port and the collets when a first predetermined pressure differential is created across the ball seat. The plug is capable of being expelled from the flow

passage when a second predetermined pressure differential is created across the plug.

The method further includes the steps of positioning the sand control screen in a predetermined axial position in the wellbore relative to the formation and forcing a gravel pack slurry through the production tubing, into the flow passage, through the flow port, into the wellbore, and into an annular area radially intermediate the sand control screen and the formation. The first predetermined pressure differential is created across the ball seat by sealingly engaging a ball with the ball seat and applying pressure to the production tubing. The second predetermined pressure differential is created across the plug by applying pressure to the production tubing after the first predetermined pressure differential is created.

The use of the disclosed apparatus and methods of using same permits larger screens to be used in through-tubing gravel pack operations, provides larger flow areas through which to pump the gravel, eliminates separate screen installation and removal by wireline or slickline operations, and permits convenient removal of the tubing while the screen and gravel pack remain undisturbed in the well.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A–1B are cross-sectional views of a first apparatus embodying principles of the present invention;

FIGS. 2A–2B are highly schematicized cross-sectional views of a method embodying principles of the present invention, using the first apparatus;

FIGS. 3A–3B are cross-sectional views of a second apparatus embodying principles of the present invention;

FIGS. 4A–4B are cross-sectional views of a third apparatus embodying principles of the present invention;

FIGS. 5A–5C are cross-sectional views of a fourth apparatus embodying principles of the present invention; and

FIGS. 6A–6B are cross-sectional views of a sixth apparatus embodying principles of the present invention.

DETAILED DESCRIPTION

The following descriptions of preferred embodiments of the present invention describe use of the embodiments in gravel packing operations in subterranean wellbores. It is to be understood, however, that apparatus and methods embodying principles of the present invention may be utilized in other operations, such as fracturing or acidizing operations.

Illustrated in FIGS. 1A and 1B is a gravel pack apparatus 10 which embodies principles of the present invention. In the following detailed description of the apparatus 10 representatively illustrated in FIGS. 1A and 1B, and subsequent apparatus, methods, and figures described hereinbelow, directional terms such as “upper”, “lower”, “upward”, “downward”, etc. will be used in relation to the apparatus 10 as it is depicted in the accompanying figures. It is to be understood that the apparatus 10 and subsequent apparatus and methods described hereinbelow may be utilized in vertical, horizontal, inverted, or inclined orientations without deviating from the principles of the present invention.

The apparatus 10 includes a tubular upper housing 12, a tubular lower housing 14, an expandable ball seat 16, a plug 18, collets 20, and a tubular sleeve 22. FIG. 1A shows the apparatus 10 in a configuration in which it is run into the wellbore prior to the gravel pack operation. FIG. 1B shows the apparatus 10 in a configuration subsequent to the gravel pack operation. Comparing FIG. 1B to FIG. 1A, note that the

expandable ball seat 16 has expanded radially outward within the upper housing 12, the sleeve 22 has been shifted downward within the upper housing, the plug 18 has been ejected out of the sleeve, and the lower housing 14 has separated from the upper housing 12.

When initially run into the wellbore prior to the gravel pack operation, as shown in FIG. 1A, the apparatus 10 is installed between the production tubing and the sand control screen (not shown in FIGS. 1A and 1B). The tubing is threadedly and sealingly attached to the upper housing 12 at upper connector 24. An interior axial flow passage 26 is thus placed in fluid communication with the interior of the production tubing. The screen is threadedly and sealingly attached to the lower housing 14 at lower end 28. Plug 18 in sleeve 22 prevents fluid communication between the interior of the production tubing and the interior of the screen via the flow passage 26.

Plug 18 prevents gravel, pumped down the tubing from the earth's surface, from filling the interior of the sand screen during the gravel pack operation. The plug 18 is later ejected, as shown in FIG. 1B, to permit flow of fluids from the interior of the screen, through the flow passage 26, and into the production tubing for transport to the earth's surface. A circumferential seal 34 sealingly engages the plug 18 and sleeve 22 and permits a pressure differential to be created across the plug to shear shear pins 36 which extend radially through the sleeve 22 and into the plug.

Radially extending ports 30 on the sleeve 22 are initially aligned with radially extending ports 32 on the upper housing 12, permitting fluid communication between the flow passage 26 and the wellbore external to the apparatus 10. During the gravel pack operation, gravel may be pumped through the ports 30 and 32 and into the annular area between the screen and the casing. Radially extending and circumferentially spaced splines 33 formed on lower housing 14 permit fluid flow longitudinally between the wellbore external to the upper housing 12 and the wellbore below the lower housing as further described below.

The aligned relationship of the ports 30 and 32 is releasably secured by shear pins 38 threadedly installed radially through the upper housing 12 and into the sleeve 22. When shear pins 38 are sheared, sleeve 22 is permitted to move downwardly until radially sloping shoulder 40 on the sleeve 22 contacts radially sloping shoulder 42 on the upper housing 12.

When sleeve 22 has been downwardly shifted, as shown in FIG. 1B, circumferential seals 44, which sealingly engage the sleeve and upper housing 12, straddle the ports 32 on the upper housing 12 and prevent fluid communication between the flow passage 26 and the wellbore external to the apparatus 10. Circumferential seals 46, 48, and 50 sealingly engage the upper connector 24 and an upper end 52 of the upper housing 12, the sleeve 22 and the upper housing, and the sleeve and the lower housing 14, respectively, also preventing fluid communication between the flow passage 26 and the wellbore external to the apparatus 10.

Sleeve 22 is downwardly shifted within the upper housing 12 by the expandable ball seat 16. The expandable ball seat 16 is of conventional construction and is in a radially compressed configuration, as viewed in FIG. 1A, when installed into the upper connector 24. Upwardly facing seal surface 54 on the ball seat 16, when in the radially compressed configuration, is smaller in diameter than, and is thus capable of sealingly engaging, a ball 56 dropped or pumped down through the production tubing. It is to be understood that the ball 56 would preferably not be dropped

through the production tubing during the gravel pack operation as it would interfere with the pumping of gravel through the apparatus 10. The ball 56 is preferably dropped through the production tubing when the gravel pack operation has been completed and it is desired to shift the sleeve 22 to close ports 32.

When the ball 56 sealingly engages the seal surface 54, a pressure differential may be created across the ball seat 16 by applying pressure to the interior of the production tubing at the earth's surface. Such a pressure differential downwardly biases the ball seat 16 against the sleeve 22, forcing radially sloping surface 57 on the ball seat 16 against radially sloping surface 58 on the sleeve. The contact between the sloping surfaces 57 and 58 further biases the ball seat 16 radially outward.

When sufficient pressure differential has been created across the ball seat 16, shear pins 38 shear, permitting the sleeve 22 to downwardly shift, as described above, and permitting the ball seat 16 to expand radially outward into radially enlarged inner diameter 60 within the upper housing 12. Such expansion of the ball seat 16 causes the seal surface 54 to have an inner diameter larger than that of the ball 56, which permits the ball to pass through the ball seat and the flow passage 26 to the plug 18. Thus, when the plug 18 is later expelled from the sleeve 22, as shown in FIG. 1B and described above, the ball 56 will also be expelled.

Lower housing 14 is initially coaxially attached to the upper housing 12, as shown in FIG. 1A, with collets 20 which are threadedly installed onto the upper housing. Radially enlarged outer diameter 62 on the sleeve 22 biases the collets 20 radially outward so that radially extending projections 64 on the collets are radially larger than reduced inner diameter 66 on the lower housing 14. When, however, the sleeve 22 has been downwardly shifted, as shown in FIG. 1B, the collets 20 are no longer radially outwardly biased by diameter 62 on the sleeve, and the collets are permitted to flex radially inward. Inner diameter 66 on the lower housing 14 may then pass over the projections 64, permitting the lower housing to separate from the upper housing 12.

In a preferred mode of operation, the apparatus 10 is installed between the production tubing and the sand control screen as described above. During the gravel pack operation, gravel is pumped down through the tubing and into flow passage 26. The gravel exits through the aligned ports 30 and 32 and flows into the wellbore. When the gravel pack operation is completed, the ball 56 is dropped or pumped down through the tubing to the ball seat 16. Pressure is applied to the tubing at the surface until a first predetermined pressure differential is created across the ball seat 16, shearing the shear pins 38 and forcing the sleeve 22 to shift downward. At this point, ports 32 are closed, preventing fluid communication between the wellbore and the flow passage 26, and collets 20 are no longer biased radially outward. The ball 56 passes through the ball seat 16. A second predetermined pressure differential is then created across the plug 18 by applying pressure to the tubing at the earth's surface, thereby shearing shear pins 36, and expelling the plug 18 and the ball 56 from the sleeve 22. The tubing may be removed from the wellbore when desired, without displacing or otherwise disturbing the screen or gravel pack.

Turning now to FIGS. 2A and 2B, a method 70 of using the apparatus 10 is representatively illustrated. It is to be understood that, with suitable modifications, other apparatus may be utilized in method 70, including other apparatus described hereinbelow, without departing from the principles of the present invention.

FIG. 2A shows the apparatus 10 operatively installed between production tubing 72, which extends to the earth's surface and is attached to the upper housing 12, and sand control screen 74. The screen 74, apparatus 10, and tubing 72 are lowered into wellbore 76, which intersects formation 78 and is lined with protective casing 80. A conventional tubing hanger 82 has previously been set in the casing 80 a predetermined distance above the formation 78. As the screen 74, apparatus 10, and tubing 72 are lowered into the wellbore, splines 33 on the lower housing 14 engage the tubing hanger 82, thereby positioning the screen 74 in the wellbore 76 opposite the formation 78. Alternatively, splines 33 could engage, for example, a nipple (not shown) disposed in a string of production tubing (not shown), or the nipple could be suspended from a packer (not shown) set in the casing 80.

A gravel pack slurry 84 is then pumped down the tubing 72 from the earth's surface. The slurry 84 enters the flow passage 26 of the apparatus 10 and then exits the apparatus through open ports 32. The slurry 84 then flows downwardly in the wellbore 76 and passes between the splines 33 and the tubing hanger 82. From the tubing hanger 82, the slurry 84 enters an annular area 86 below the tubing hanger and radially intermediate the screen 74 and the casing 80.

Slurry 84 is pumped into the annular area 86 until it forms a gravel pack 88 as shown in FIG. 2B. The ball 56 is then dropped or pumped down the tubing 72, the ball sealingly contacting the ball seat 16. Pressure is applied to the tubing 72 to shift the sleeve 22 downward and close ports 32 as described above. The collets 20 are also no longer biased radially outward after the sleeve 22 is downwardly shifted, but the upper housing 12 is not yet separated from the lower housing 14.

Pressure is again applied to the tubing 72 to expel the plug 18 and ball 56 from the sleeve 22 as described above. The plug 18 and ball 56 then drop into the screen 74 as shown in FIG. 2B. At this point the tubing 72 is in fluid communication with the screen 74 and fluids 90 may flow from the formation 78, through the gravel pack 88 in the annular area 86, through the screen 74, through the flow passage 26 of the apparatus 10, and upwardly through the tubing 72 to the earth's surface.

If desired, the tubing 72 may be conveniently removed from the wellbore 76 by raising the tubing to separate the upper housing 12 from the lower housing 14. The lower housing 14 remains in the wellbore 76, supporting the screen 74 opposite the formation 78 in the gravel pack 88 as shown in FIG. 2B. The screen 74 and gravel pack 88 are not disturbed when the tubing 72 is removed from the wellbore 76.

Note that, in the above-described method 70, screen 74 is not required to pass through the tubing 72 and, therefore, has an outer diameter which is limited only by the casing 80 or tubing hanger 82. Note also, that a relatively large flow area is available for slurry 84 to flow between the lower housing 14 and the tubing hanger 82 via the splines 33. Additionally, no separate wireline or slickline operation is needed in method 70 to position or remove the screen 74.

Turning now to FIGS. 3A and 3B, an apparatus 10a is shown which is a modified form of the apparatus 10 shown in FIGS. 1A-2B. Elements of apparatus 10a which are similar to those elements previously described are indicated in FIGS. 3A and 3B with the same reference numerals, but with an added suffix "a".

Apparatus 10a functions similar to apparatus 10, the major difference being that ports 32a are initially closed, as

shown in FIG. 3A. Ports 32a are axially displaced from ports 94 on sleeve 96. Circumferential seal 98 sealingly engages the sleeve 96 and upper housing 12a and is disposed axially intermediate ports 94 and 32a, thereby preventing fluid communication between the ports.

When the sleeve 96 is downwardly shifted, as shown in FIG. 3B, ports 94 and 32a are aligned and fluid communication is established between the flow passage 26a and the wellbore external to the apparatus 10a. It will be readily appreciated by one skilled in the art that if the flow passage 26a is in fluid communication with the wellbore and the interior of lower end 28a is in fluid communication with the wellbore, a pressure differential cannot be created across the plug 18a to expel the plug and ball 56a from the sleeve 96. Thus, if the plug 18a is desired to be expelled from the sleeve 96 of apparatus 10a by pressure differential created across the plug, a means, such as gravel pack 88 (see FIG. 2B), to restrict fluid communication between the flow passage 26a and the interior of the lower end 28a via the wellbore must be utilized.

Thus, apparatus 10a is useful in circumstances in which it is desired to run the apparatus into the wellbore with ports 32a initially closed. The ports 32a may then be opened by dropping or pumping ball 56a down the tubing and applying a predetermined pressure to shear shear pins 38a and downwardly shift the sleeve 96.

When sleeve 96 has been shifted downward, ports 32a and 94 are aligned and permit flow therethrough, and collets 20a are no longer radially outwardly biased by enlarged outer diameter 62a. The upper housing 12a may then be separated from lower housing 14a, and, if a means to seal flow passage 26a against fluid communication with lower end 28a has been utilized, the ball 56a and plug 18a may be expelled from the sleeve 96 by applying a second pressure differential to shear shear pins 36a.

Illustrated in FIGS. 4A and 4B is an apparatus 10b which is another modified form of the apparatus 10 shown in FIGS. 1A-2B. Elements of apparatus 10b which are similar to those elements previously described are indicated in FIGS. 4A and 4B with the same reference numerals, but with an added suffix "b".

Apparatus 10b functions similar to apparatus 10, the major difference being that there are no ports 30 and 32 and no plug 18. The flow passage 26b extends axially through the apparatus 10b, permitting flow therethrough at all times, except for when ball 56b is dropped or pumped down to ball seat 16b and engages seal surface 54b. Circumferential seal 102 sealingly engages sleeve 100 and upper housing 12b and is disposed axially intermediate shear pins 38b and upper connector 24b.

The sleeve 100 is shifted downward by pumping or dropping ball 56b into the apparatus 10b so that the ball 56b sealingly engages the ball seat 16b. A predetermined pressure is created across the ball seat 16b, shearing shear pins 38b. The ball seat 16b then expands radially outward and ball 56b is permitted to pass through flow passage 26b.

When sleeve 100 is downwardly shifted, as shown in FIG. 4B, collets 20b are no longer radially outwardly biased by enlarged outer diameter 62b. The upper housing 12b may then be separated from lower housing 14b. Thus, apparatus 10b is useful in circumstances in which it is desired to run the apparatus into the wellbore with no fluid communication between the flow passage 26b and the wellbore external to the apparatus 10b, or when such fluid communication is otherwise provided, and then to separate the upper housing 12b from the lower housing 14b.

FIGS. 5A–5C show an apparatus 10c which is yet another modified form of the apparatus 10 shown in FIGS. 1A–2B. Elements of apparatus 10c which are similar to those elements previously described are indicated in FIGS. 5A–5C with the same reference numerals, but with an added suffix “c”.

Apparatus 10c functions similar to apparatus 10, the major difference being the inclusion of annular ring 106 in annular space 108 axially intermediate sloping surfaces 40c and 42c, and radially intermediate the sleeve 22c and upper housing 12c. Annular ring 106 has upper and lower radially sloping surfaces 110 and 112, respectively, and is releasably secured by shear pins 114 against axial movement relative to the upper housing 12c. As will be readily appreciated by consideration of the following description, annular ring 106 permits the steps of closing the ports 32c and separating the housings 12c and 14c to be performed separately.

When the sleeve 22c is downwardly shifted, as shown in FIG. 5B, ports 32c are closed, preventing fluid communication between the flow passage 26c and the wellbore external to the apparatus 10c. In this configuration of the apparatus 10c, sloping shoulder 40c on sleeve 22c is in contact with sloping shoulder 110 of annular ring 106. The ball seat 16c is expanded radially outward, permitting the ball 56c to pass through the flow passage 26c. Plug 18c and ball 56c may be expelled from the sleeve 22c by creating a sufficient differential pressure across the plug to shear shear pins 36c. However, unlike apparatus 10 as shown in FIG. 1B, the upper housing 12c may not be separated from the lower housing 14c with the apparatus 10c in the configuration shown in FIG. 5B, because the collets 20c remain radially outwardly biased by outer diameter 62c on the sleeve 22c.

In order to separate upper housing 12c from lower housing 14c, a second ball 116 is dropped or pumped down into the apparatus 10c. The ball 116 has a larger diameter than the first ball 56c, but is still able to pass through the expanded ball seat 16c as shown in FIG. 5C. The ball 116 has a diameter which is, however, too large to pass through the sleeve 22c. Instead, the ball 116 sealingly engages a circumferential seal surface 118 on the sleeve 22c, disposed adjacent the sloping surface 58c. A pressure differential may now be created across the ball 116 to downwardly bias the sleeve 22c and shear shear pins 114. The sleeve 22c and annular ring 106 may then shift downwardly until sloping shoulder 112 contacts sloping shoulder 42c. When the sleeve 22c is thus further shifted downwardly, outer diameter 62c no longer radially outwardly biases the collets 20c and the upper housing 12c may be separated from the lower housing 14c. Additionally, ports 32c are again opened, permitting fluid communication between the wellbore and the apparatus 10c interior above the ball 116.

In a preferred mode of operation, the apparatus 10c is installed between the production tubing and the sand control screen as described above. During the gravel pack operation, gravel is pumped down through the tubing and into flow passage 26c. The gravel exits through the aligned ports 30c and 32c and flows into the wellbore. When the gravel pack operation is completed, the ball 56c is dropped or pumped down through the tubing to the ball seat 16c. Pressure is applied to the tubing at the surface until a first predetermined pressure differential is created across the ball seat 16c, shearing the shear pins 38c and forcing the sleeve 22c to shift downward. At this point, ports 32c are closed, preventing fluid communication between the wellbore and the flow passage 26c. The ball 56c passes through the ball seat 16c. A second predetermined pressure differential is then created

across the plug 18c by applying pressure to the tubing at the earth's surface, thereby shearing shear pins 36c, and expelling the plug 18c and the ball 56c from the sleeve 22c. The well may then go into production, with fluids flowing from the formation, through the gravel pack, through the screen, and upwardly through the flow passage 26c and the tubing to the earth's surface. If it is later desired to remove the tubing from the wellbore without displacing or otherwise disturbing the screen and gravel pack, a second ball 116 is dropped or pumped down the tubing and a third predetermined pressure differential is created across the ball to shear shear pins 114. The sleeve 22c then shifts further downwardly, permitting the collets 20c to flex radially inward. The tubing may then be removed from the wellbore, any fluid remaining in the tubing being able to flow out of the re-opened ports 32c into the wellbore during the tubing's removal.

Thus, apparatus 10c is useful in circumstances in which it is desired to run the apparatus into the wellbore with ports 32c initially open, perform the gravel pack operation, close the ports, and expel the plug 18c and ball 56c before putting the well into production, but it is not desired to concurrently release the upper housing 12c for separation from the lower housing 14c. This permits the tubing, apparatus 10c, and screen to later be removed from the wellbore together (the upper and lower housings 12c and 14c, respectively, remaining attached), or, if it is desired to remove the tubing, but not the screen, from the wellbore, the second ball 116 may be dropped or pumped down through the tubing to separate the upper and lower housings 12c and 14c, respectively.

FIGS. 6A and 6B show another apparatus 124 embodying principles of the present invention. The apparatus 124 includes an upper housing 126, a lower housing 128, an expandable ball seat 130, a plug 132, collets or lugs 134, and a sleeve 136. FIG. 6A shows the apparatus 124 in a configuration in which it is run into the wellbore prior to the gravel pack operation. FIG. 6B shows the apparatus 124 in a configuration subsequent to the gravel pack operation. Comparing FIG. 6B to FIG. 6A, note that the expandable ball seat 130 has expanded radially outward within the lower housing 128, the sleeve 136 has been shifted downward within the lower housing, the plug 132 has been ejected, and the lower housing 128 has separated from the upper housing 126.

When initially run into the wellbore prior to the gravel pack operation, as shown in FIG. 6A, the apparatus 124 is installed between the production tubing and the sand control screen. The tubing is threadedly and sealingly attached to the upper housing 126 threaded connection 137. An interior axial flow passage 138 is thus placed in fluid communication with the interior of the production tubing. The screen is threadedly and sealingly attached to the lower housing 128 at threaded connection 140. Plug 132 is retained in an annular sleeve 142 disposed in an inner diameter 144 of lower housing 128 and prevents fluid communication between the interior of the production tubing and the interior of the screen via the flow passage 138. Circumferential seal 146 sealingly engages the annular sleeve 142 and inner diameter 144.

The plug 132 prevents gravel, pumped down the tubing from the earth's surface, from filling the interior of the sand screen during the gravel pack operation. The plug 132 is later ejected, as shown in FIG. 6B, to permit flow of fluids from the interior of the screen, through the flow passage 138, and into the production tubing for transport to the earth's surface. A circumferential seal 148 sealingly engages the plug 132 and sleeve 142 and permits a pressure differential

to be created across the plug to shear shear pins 150 which extend radially through the sleeve 142 and into the plug.

Radially extending ports 152 formed through the lower housing 128 are initially open, as shown in FIG. 6A, permitting fluid communication between the flow passage 138 and the wellbore external to the apparatus 124. During the gravel pack operation, gravel may be pumped through the ports 152 and into the annular area between the screen and the casing.

Shear pins 154, extending radially through the upper housing 126 and the sleeve 136, releasably secure the sleeve against axial movement relative to the upper housing. When shear pins 154 are sheared, sleeve 136 is permitted to move downwardly until shoulder 156 on the sleeve 136 contacts shoulder 158 formed on the lower housing 128.

When sleeve 136 has been downwardly shifted, as shown in FIG. 6B, circumferential seals 160 straddle the ports 152 on the lower housing 128 and prevent fluid communication between the flow passage 138 and the wellbore external to the apparatus 124. Circumferential seal 162 sealingly engages the upper housing 126 and an upper end 164 of the lower housing 128, also preventing fluid communication between the flow passage 138 and the wellbore external to the apparatus 124.

Sleeve 136 is downwardly shifted within the lower housing 128 by a first predetermined pressure differential created across the expandable ball seat 130. The expandable ball seat 130 is of conventional construction and is in a radially compressed configuration, as viewed in FIG. 6A, when installed into the sleeve 136. Upwardly facing seal surface 166 on the ball seat 130, when in the radially compressed configuration, is smaller in diameter and is thus capable of sealingly engaging a ball 168 dropped or pumped down through the production tubing. It is to be understood that the ball 168 would preferably not be dropped through the production tubing during the gravel pack operation as it would interfere with the pumping of gravel through the apparatus 124. The ball 168 is preferably dropped through the production tubing when the gravel pack operation has been completed and it is desired to shift the sleeve 136 to close ports 152.

When the ball 168 sealingly engages the seal surface 166, a pressure differential may be created across the ball seat 130 by applying pressure to the interior of the production tubing at the earth's surface. Such a pressure differential downwardly biases the ball seat 130 against a ring 170, forcing radially sloping surface 172 formed on the ball seat 130 against radially sloping surface 174 on the ring. The contact between the sloping surfaces 172 and 174 further biases the ball seat 130 radially outward. The ring 170 is releasably secured against axial movement within the sleeve 136 with shear pins 176 extending radially through the sleeve and the ring.

When a first predetermined pressure differential has been created across the ball seat 130, shear pins 154 shear, permitting the sleeve 136 to downwardly shift, as described above. Lower housing 128 is initially coaxially attached to the upper housing 126, as shown in FIG. 6A, with lugs 134 which are installed radially through openings 178 formed on the upper housing. Radially reduced outer diameter 180 on the sleeve 136 biases the lugs 134 radially outward so that they are radially larger than reduced inner diameter 182 on the lower housing 128. When, however, the sleeve 136 has been downwardly shifted, as shown in FIG. 6B, the lugs 134 are no longer radially outwardly biased by diameter 180 on the sleeve, and the lugs are permitted to displace radially

inward. Inner diameter 182 on the lower housing 128 may then pass over the lugs 134, permitting the lower housing to separate from the upper housing 126.

Application of a second predetermined differential pressure across the ball seat 130, greater than the first pressure differential, will then cause the shear pins 176 to shear and permit the ball seat and ring 170 to downwardly shift and move axially into the inner diameter 144 of the lower housing 128, as shown in FIG. 6B. The ball seat 130 is thus permitted to expand radially outward into the inner diameter 144. Such expansion of the ball seat 130 causes the seal surface 166 to have a diameter larger than that of the ball 168, which permits the ball to pass through the ball seat and the flow passage 138 to the plug 132. Thus, when the plug 132 is later expelled from the annular sleeve 142, as shown in FIG. 6B and described above, the ball 168 will also be expelled.

In a preferred mode of operation, the apparatus 124 is installed between the production tubing and the sand control screen as described above. During the gravel pack operation, gravel is pumped down through the tubing and into flow passage 138. The gravel exits through the ports 152 and flows into the wellbore. When the gravel pack operation is completed, the ball 168 is dropped or pumped down through the tubing to the ball seat 130. Pressure is applied to the tubing at the surface until a first predetermined pressure differential is created across the ball seat 130, shearing the shear pins 154 and forcing the sleeve 136 to shift downward. At this point, ports 152 are closed, preventing fluid communication between the wellbore and the flow passage 138, and lugs 134 are no longer biased radially outward. A second predetermined pressure differential is then created across the ball seat 130, causing the shear pins 176 to shear and forcing the ring 170 and ball seat 130 to shift downward into diameter 144 of the lower housing 128 and permitting the ball seat to expand radially outward. The ball 168 passes through the expanded ball seat 130. A third predetermined pressure differential is then created across the plug 132 by applying pressure to the tubing at the earth's surface, thereby shearing shear pins 150, and expelling the plug 132 and the ball 168 from the sleeve 142. The tubing may then be removed from the wellbore when desired, without displacing or otherwise disturbing the screen or gravel pack.

The foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the spirit and scope of the present invention being limited solely by the appended claims.

What is claimed is:

1. Apparatus positionable in a subterranean wellbore, comprising:

- a tubular first housing having an inner diameter;
- a tubular second housing having an inner diameter, said second housing being coaxially disposed relative to said first housing, an end of said first housing being proximate an end of said second housing;
- an expandable ball seat;
- a plurality of collets extending axially between said first housing end and said second housing end, said collets releasably securing said first housing against axial displacement relative to said second housing;
- a flow passage extending through said first and second housings; and
- a tubular sleeve coaxially disposed within said first and second housings, said sleeve having an outer diameter radially inwardly adjacent said collets, said sleeve outer diameter radially outwardly biasing said collets, and

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said sleeve being disposed adjacent said ball seat, such that said sleeve axially displaces relative to said collets when a first predetermined pressure differential is created across said ball seat,

said ball seat expanding when said sleeve axially displaces relative to said collets, 5

whereby, said collets are released for radially inward displacement when said first predetermined pressure differential is created across said ball seat, said sleeve being axially displaced relative to said collets. 10

2. The apparatus according to claim 1, further comprising a first shear member releasably securing said sleeve against axial displacement relative to said first housing, said first shear member releasing said sleeve for axial displacement relative to said first housing when said first predetermined pressure differential is created across said ball seat. 15

3. The apparatus according to claim 1, wherein said collets are attached to said first housing end and each of said collets have a radially outwardly extending projection formed thereon, and wherein said second housing inner diameter is formed on said second housing radially inward from said projections and axially intermediate said first housing end and said projections. 20

4. The apparatus according to claim 3, wherein said projections are capable of radially inward displacement when said sleeve displaces axially relative to said collets and said collets are not radially outwardly biased by said sleeve outer diameter. when a second predetermined pressure differential is created across said plug. 25

5. The apparatus according to claim 1, wherein said second housing further has a series of circumferentially spaced splines formed on an exterior surface thereof. 30

6. Apparatus positionable in a subterranean wellbore, comprising:

a tubular first housing having an inner diameter;

a tubular second housing having an inner diameter, said second housing being coaxially disposed relative to said first housing, an end of said first housing being proximate an end of said second housing; 35

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an expandable ball seat in a radially compressed configuration thereof;

a plurality of collets extending axially between said first housing end and said second housing end, said collets releasably securing said first housing against axial displacement relative to said second housing;

a flow passage extending through said first and second housings; and

a tubular sleeve coaxially disposed within said first and second housings, said sleeve having an outer diameter radially inwardly adjacent said collets, said sleeve outer diameter radially outwardly biasing said collets, and said sleeve being disposed adjacent said ball seat, such that said sleeve is capable of axial movement relative to said collets when a first predetermined pressure differential is created across said ball seat, 5

said ball seat being capable of expanding to a radially expanded configuration thereof when said sleeve and said ball seat are displaced axially relative to said first housing and said ball seat enters said first housing inner diameter, 10

whereby, said collets are released for radially inward displacement when said first predetermined pressure differential is created across said ball seat, said sleeve being axially displaced relative to said collets. 15

7. The apparatus according to claim 6, wherein said ball seat has a first radially sloping surface formed thereon and said sleeve has a second radially sloping surface formed thereon, such that when said ball seat is biased toward said sleeve, said first radially sloping surface is in contact with said second radially sloping surface and said ball seat is radially outwardly biased. 20

8. The apparatus according to claim 6, wherein said ball seat is capable of ball sealment thereto when in said radially compressed configuration thereof and is incapable of ball sealment thereto when in said radially expanded configuration thereof. 25

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